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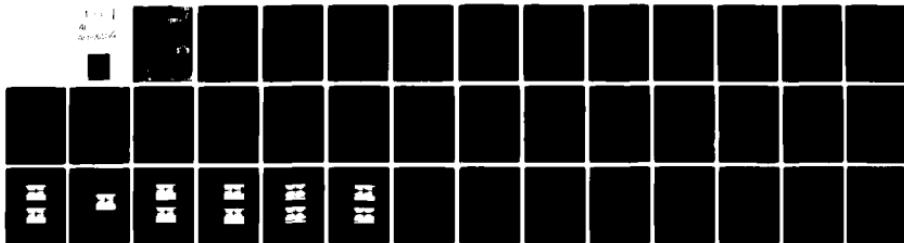
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AN INVESTIGATION OF HF PROPAGATION OVER AN AURORAL SUB-AURORAL --ETC(U)
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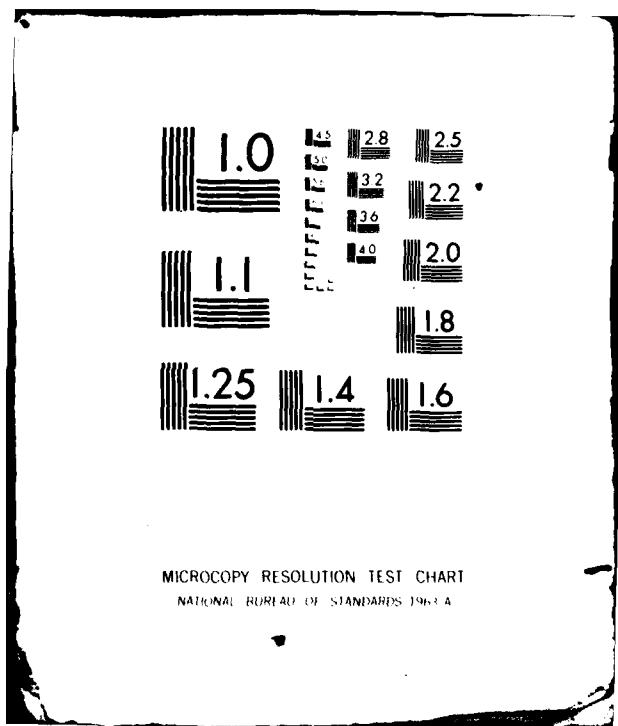
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ROYAL AIRCRAFT ESTABLISHMENT

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AN INVESTIGATION OF HF PROPAGATION OVER AN AURORAL SUB-AURORAL PATH

by

J. B. Dawes

SUMMARY

Methods of determining the usable frequencies over a particular auroral sub-auroral path such that digital data may be sent uncorrupted, are described. Tests took place between April and July 1980 using transmissions between Northern Norway and Southern England. Computer programs were used in order to determine the viability of linearly interpolating the ionospheric propagation parameters from sub-auroral areas to an auroral or polar zone. One of these programs was written for this project and is included. The others are in general use and are, therefore, not listed. It was found that interpolation of the ionospheric parameters over these zones has limited use.

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1 INTRODUCTION

The ionosphere may be used to propagate HF radio waves from one position on the Earth's surface to a distant position. The way in which this propagation occurs is hard to predict due to the fact that the ionosphere is continually changing. Thus the propagation varies with geographical location, eg the polar ionosphere is vastly different from that at the equator¹⁻³.

The aim of this investigation was to examine a particular auroral sub-auroral path from Bodø in Northern Norway, to the RAE receiving station at Cobbett Hill. The method involved firstly flight trials which took place in April 1980. Using results from the airborne trials, ionosonde data from Slough, Bucks, and South Uist in the Hebrides, computer programs predicted the modes of propagation likely along the path for specified times. The data from Slough and South Uist enabled an estimate to be made of the viability of interpolating the ionospheric parameters into an auroral zone. It is already known that it is feasible to use interpolation in mid-latitude cases. Secondly tests were also performed on a point-to-point basis over the same path in June and July 1980 using a range of frequencies, one near the maximum usable frequency (MUF) another near the lowest usable frequency (LUF) and a third between the two. The aim of this was to investigate, by photographing a series of ionospherically propagated single pulses, which methods of propagation were probable when using a particular frequency.

Sunspot number, which has a one-to-one correlation with magnetic storms and greatly affects the ionosphere, varies with a fairly regular eleven year cycle. At the time of these trials, the sunspot number was very high, possibly even at the peak of the cycle. It is, therefore, necessary to note this fact when considering the frequencies which may be used for HF propagation⁴, as the MUF and LUF will be greatly affected by the sunspot activity and magnetic storms.

2 BACKGROUND2.1 Ionospheric predictions

It is possible by use of computer programs to predict, on a statistical basis, which modes of propagation are likely on a particular day under given conditions. Programs such as APPLAB⁵ and BLUEDECK⁶ are able to predict whether E or F modes are likely to be present on a given path, at a particular time for a given frequency. They do not always agree, however, as not all parameters may be catered for in the data store of these programs. APPLAB is deficient in that it does not predict mixed modes. BLUEDECK attempts to predict mixed modes, but can only predict IF,IE or IE,IF modes, more complex mixed modes are not catered for. Neither program predicts the presence of Sporadic E, as this is an extremely variable propagation mechanism. APPLAB allows for the existence of high and low angled paths (see Fig 1a). As may be seen, the angle at the transmitter is much greater for a high than for a low angled path. There is a corresponding increase in the arrival angle at the receiving antenna.

Some input parameters are required to enable the computer to calculate these predictions. Typically, it is necessary to know the coordinates of the transmitter and receiver, the frequency used, the date, the time of day, the sunspot number, the polarisation of the antennas and other data. In APPLAB, for example, data such as f_0E , f_0F_2 , $M(3000)F_2$ and $h'F$ is required. These four parameters are measured by ionosondes and the values used in the APPLAB prediction may be either taken from a store, or input as data. The values f_0F_2 and f_0E are the 'critical' frequencies of the reflections of vertically incident ordinary waves from the F_2 and E layers respectively. $M(3000)F_2$ is the maximum usable frequency factor (M factor) for the F_2 layer, over a distance of 3000 km. The M factor is the ratio of the maximum or penetration frequency to the critical frequency. $h'F$ is the apparent height at which a wave is reflected from the F layer (Fig 2). The actual height is h , but by extrapolating the wave as if it is reflected from a 'mirror' instead of being continuously refracted, then the 'mirror' is at a height h' .

By processing all the available data, the program predicts the modes which are likely to occur, and gives information as to the characteristics of the mode. This information includes the elevation angle at the transmitter and the receiver, the group delay, the signal-to-noise ratio, the reliability and other cogent factors. From this information, one can judge the optimum frequency to use along a particular path, at the given time.

2.2 Data propagation

HF is defined as the band of frequencies between 3-30 MHz and not all this band is available for use at any one time due to the factors affecting the MUF and LUF. Thus this narrow band where radio waves are propagated is in high demand. It is necessary that we try and utilize the frequency spectrum to the best advantage. However, near the LUF, for example, it may be expected that data transmitted in digital form would be corrupted due to multipath propagation. It is necessary, therefore, to investigate how great the corruption is, and whether this necessitates a more stringent limiting of the usable frequencies. To do this, a data generator was constructed which would produce a BARKER and a data sequence at signalling rates of 600 and 75 baud, together with a series of single pulses for sounding purposes (Fig 3). The data sequence is a pseudo-random sequence of 1023 bits. The frame synchronizing sequence used is a BARKER series of pulses, chosen to have a low correlation factor with noise. If the received BARKER sequence is satisfactorily received, then equipment at the receiving station would be able to 'lock' onto it and thus achieve frame synchronization. It would then be possible to see how many errors in the 1023 bit data series were caused by the propagation via the ionosphere⁷. A high proportion of errors might indicate that the frequency used was not suitable for the transmission of data. The single pulse signal when viewed by means of an oscilloscope would enable the modes of propagation present to be resolved, and so enable one to make judgments of the relationships between the occurrence of multimode propagation and error rate.

3 TRIALS PROCEDURE

3.1 Flight trials

Tests were conducted between the Radio Department BAC 1-11 flying laboratory operating out of Bodø in Northern Norway and the RAE Radio Station at Cobbett Hill. The aircraft was equipped with the necessary apparatus in order to receive or transmit signals having a format suitable for computer analysis. The aircraft followed a flight path as shown by the map (Fig 4). In order to find the aircraft's position at specified times, it was necessary to interpolate between the logged coordinates. To do this a subroutine COORD1 was written for use on the PDP11 which evaluates coordinates of N equally spaced points along the great circle path between two known positions. It was then possible to determine where the aircraft was at any particular five minute interval. Relevant points are plotted on the map shown. COORD1 was called up by IONPB (see the Appendix) where IONPB is a program which given the data comprising the time (GMT) of HF sounding and of first ionosonde data together with the geographical separation of the ionosonde sounding stations and drawing upon its input file of f_0F_2 , f_0E , $M(3000)F_2$ and $h'F$ for each of the soundings, will produce these quantities as required at specific locations by linearly interpolating the ionospheric data. Values were produced using ionosonde data from vertical sounders at Slough, and at South Uist. This data together with that obtained for the aircraft position during the trials were then placed into the APPLAB program. Several runs of APPLAB were produced for specific times and frequencies using median ionospheric values where the data of f_0F_2 , f_0E , $M(3000)F_2$ and $h'F$ were input in one case and taken from predictions in the program data store in other cases. Information was also fed into the APPLAB program concerning the polarization of the antennas. In one case the polarizations were the same, i.e vertical, in the others they were dissimilar, one was horizontal the other vertical. Also obtained, when required, were predictions for the upper and lower decile stored data values, as well as for the median value. These values were obtained by the computer fitting a normal distribution curve to the data store of f_0E , f_0F_2 , $h'F$ and $M(3000)F_2$.

From the information received by using the programs, it is possible to assess the method of propagation of the signal between the transmitter and receiver. The data input from Slough and South Uist was required in order to observe the feasibility of measuring the ionosphere and extrapolating northwards into the auroral and polar zones.

During the flight trials, the receiver automatic gain control (AGC) voltage was constantly monitored and recorded by the computer. The AGC signal was digitised by an A to D convertor, quantized in steps up to a maximum of 1023. The receiver AGC response having been previously calibrated⁸ a computer analysis program ICARUS used the measured values to obtain information regarding the signal and noise levels (see section 4.1).

3.2 Data trials

For the point-to-point tests carried out between the Norwegian Radio Station at Bodø and the RAE Radio Station at Cobbett Hill three frequencies were used based on APPLAB predictions: one near the MUF, one near the LUF and a third between the two. The data generator in Norway is designed to send a call sign for one minute which in

accordance with international regulations is repeated every fifteen minutes. Following this is a three minute sequence of carrier wave and single pulse signals (Fig 3).

On many occasions instead of receiving a single pulse several pulses were received after propagation by different modes. By use of a long persistence oscilloscope photographs were obtained of the pulses. A 'scope trigger unit' containing a crystal oscillator, with similar characteristics to that in the data generator in Norway, was used to synchronize the signal so that it could be seen in the centre of the oscilloscope display. Ideally the crystal oscillators should have remained in phase throughout the series of tests. Due to the frequency drift of one relative to another it was sometimes necessary to re-synchronize them again. Over a period of six weeks eight of these series of transmissions were performed per morning for three mornings a week each morning using a previously selected frequency. The remainder of the fifteen minute sequences was occupied by the transmission of BARKER and data sequences as described in section 2.2.

The photographs obtained were analysed to determine which modes were active in propagating the signal. By calibrating the time base at the start of each morning's tests, it was possible to determine the group delay between the pulses. An APPLAB and BLUEDECK run for the day concerned enabled measured data to be compared with predicted data.

The bottom trace on the picture gives an indication of the effects of the AGC system and hence a measure of the input signal level. This system is derived from the receiver and works on a negative feedback principle. When there is a strong signal the AGC level is large, when the signal is going through a fade, the level appears lower on the scope. The AGC system is required because it is desirable to have an approximately constant output from the receiver despite the fact that the input signal level varies over a large range as the signal fades and then recovers again. The AGC levels were calibrated with known input signals after the completion of each series of tests.

4 RESULTS

4.1 APPLAB and ICARUS results

Fig 1 shows typical results as obtained by using APPLAB for the date in question. They give in one case the modes which would be expected using the ionosonde data from Slough and South Uist combined (Fig 1b). That obtained from using Slough data alone has been omitted as no modes were predicted. The other cases are for (a) the predicted ionosphere with upper and lower decile values and (b) the median ionosphere (Fig 1a).

A summary of the relevant results obtained using the ICARUS analysis program are shown below for 16 April 1980 at 0488 hours GMT.

	Antenna		
	Monopole	Vertical log	Beverage
Signal median (dB μ V)	19.0	5.0	4.0
Noise median (dB μ V)	8.0	0.0	0.0
Signal/noise ratio (dB)	11.0	5.0	4.0
Average number of fades per min	144.0	0.0	0.0
Average number of fades >10 dB	14.0	0.0	0.0
Average number of fades >15 dB	13.0	0.0	0.0
Average number of fades >20 dB	3.0	0.0	0.0
Average number of fades >25 dB	0.0	0.0	0.0

4.2 Single pulse results

Fig 5 shows how the results below were obtained from the photographs.

20-6-80 (Fig 6). Frequency 18025 kHz. Time 0930-1130 hours GMT

<u>Number</u>	<u>Number of observed pulses</u>	<u>Group delay</u> Δt_1 (ms)	<u>Antennas</u>
6a	2	0.94	Horizontal log
6b	1	-	Vertical log
6c	1	-	Vertical log

23-6-80 (Fig 7). Frequency 15036 kHz. Time 0930-1130 hours GMT

<u>Number</u>	<u>Number of observed pulses</u>	<u>Group delay</u> Δt_1 (ms)	<u>Antennas</u>
7a	2	0.94	Monopole
7b	2	0.95	Horizontal log
7c	2	1.08	Vertical log
7d	2	0.81	Horizontal log

25-6-80 (Fig 8). Frequency 8975 kHz. Time 0930-1130 hours GMT

<u>Number</u>	<u>Number of observed pulses</u>	<u>Group delays (ms)</u>					<u>Antennas</u>
		Δt_1	Δt_2	Δt_3	Δt_4	Δt_5	
8a	4	0.80	1.35	1.34	-	-	Horizontal log
8b	5	0.40	1.75	1.88	-	-	Monopole
8c	6	1.48	0.67	0.54	0.54	0.67	Horizontal log
8d	6	0.68	0.53	0.81	1.48	0.67	Monopole

where $\Delta t_1 = t_2 - t_1$

$\Delta t_2 = t_3 - t_2$

$\Delta t_3 = t_4 - t_3$

$\Delta t_4 = t_5 - t_4$

$\Delta t_5 = t_6 - t_5$.

Fig 9 shows a diagrammatic representation of APPLAB and BLUEDECK results for the 25 June 1980. The results obtained are shown below.

For APPLAB:

<u>Mode</u>	<u>Field strength</u> (dB μ V)	<u>Group delay</u> (ms)	<u>Angle at transmitter</u> (deg)
1E	43.4	6.6	1.0
2E	20.5	6.7	8.8
2F ₂	33.0	9.4	41.3
2F ₂ ^H	7.8	10.2	49.3
4F ₂	17.8	14.5	61.1

For BLUEDECK:

<u>Mode</u>	<u>Field strength</u> (dB μ V)	<u>Group delay</u> (ms)	<u>Angle at transmitter</u> (deg)
1E	36.3	6.6	1.0
2E	11.0	6.7	8.9
2F	52.2	8.1	32.5
3F	48.4	13.0	57.2
4F	38.6	18.7	67.5

Fig 10, gives an equivalent diagrammatic representation of the single transmitted pulse photographs. The height of the trace is given. This is not intended to give a quantitative indication of the field strength as this would be extremely difficult to estimate until other factors were known, *eg* a detailed study of the antenna patterns that would be required, which is beyond the scope of this paper. The height of the trace is, therefore, only relevant in that it enables an estimate to be obtained of the relative amplitude(s) of the mode(s) on a particular day, at a particular frequency.

5 DISCUSSION

5.1 Analysis of flight trials

The typical example shown in section 4.1 was for the transmission on 16 April 1980 at 0488 GMT from the aircraft at $72^{\circ}37'N$, $21^{\circ}10'E$ to Cobbett Hill. The ICARUS analysis shows the results obtained from the Master and Slave measurement receiver systems. The Monopole antenna being connected usually to the 'Master' and the Vertical log or the Beverage to the 'Slave'. Facilities are available at Cobbett Hill to switch from one antenna to another during a series of tests. The average power of the received signal (relative to that of a 1μ V signal) was 11 dB for the Monopole, 5 dB for the Beverage, and 4 dB for the Vertical log. The Monopole indicated a large number of fades. In a minute period there were on average 144, indicating the probability of multimode giving destructive interference. There were no fades noticed by the Vertical log and Beverage, which is probably due to a combination of their antenna patterns and the fact that fades of less than about 5 dB are not registered by the receiver logging system.

For this time APPLAB was run using data from ionosondes at Slough, also Slough and South Uist data combined, as well as using the median predicted ionosphere. BLUEDECK was not used here. It is known to give absorption losses that are too low at auroral latitudes as it does not contain the extra auroral absorption factor which APPLAB does. Using the Slough data alone, APPLAB predicted no propagation modes, *i.e.* no signal would be received at Cobbett Hill. For the combined data, only one mode was predicted, the $1F_1$ (Fig 1b). Using the predicted ionosphere, for the median and upper decile values, two modes were predicted, the $1F_2$ and $1F_2H$ (Fig 1a). The lower decile value predicted no modes. Thus it would appear that the median and upper decile predicted ionosphere bears a greater resemblance to the actual result of a strong signal at this time. The single mode of the combined data is also not likely as the amplitude of the signal is low, and the Monopole has a high elevation angle response. The prediction of the high and low angle modes is feasible and when present may cause multipath distortion on the system using the Monopole antenna due to its good all round elevation angle response favouring the reception of both modes. Whereas the Vertical log or Beverage antennas which have good low-angle performance but reduced high angle response⁹ (see Fig 11) are more likely to favour single mode reception. APPLAB predicts a much stronger signal-to-noise ratio than actually occurred since it does not take into account man-made noises such as other transmissions.

The reason the predicted values of the ionosphere gave more reliable results than the ionosonde data is that although interpolation of the ionospheric parameters is feasible in mid-latitudes, problems arise when trying to do so over the auroral and polar zones. In mid-latitudes, the ionosphere can be defined with greater accuracy as it varies in a fairly regular diurnal pattern as it rotates with the Earth. The ionosphere in the auroral zone, however, suffers perturbations due to the precipitation of ionized particles. The polar ionosphere is greatly affected by the electric fields in the magnetosphere, and is non-uniform.

Slough and South Uist are both at sub-auroral latitudes during quiet periods. APPLAB, however, when using its stored data uses soundings as obtained from polar and auroral zones, *e.g.* Thule and Narssarssauq in Greenland, Tromsø in Norway and Reykjavík in Iceland. These values enable the predicted data to be more accurate than interpolating the ionosphere from the sub-auroral region on the actual date in question.

5.2 Analysis of transmitted single pulse signal

The photographs shown in Figs 6, 7 and 8 indicate some typical results obtained when viewing the single pulse transmissions on three different frequencies in the HF band. As may be seen, the frequency near the LUF always propagates via several modes, that near the MUF and the mid-frequency use single or two modes in order to propagate. It is impossible to positively identify the single mode, but by using APPLAB and BLUEDECK, it is possible to identify some of the modes when more than one is present.

With the frequency near the MUF, BLUEDECK predicts a strong $1E$ mode, with the possibility of a $1F$ mode. The reliability of the $1E$ is 0.82, whereas that for the $1F$ is 0.08, *i.e.* the $1F$ mode is likely to be present for a small percentage of the time.

Fig 6a shows that when the second mode is seen, the trace level of the AGC is lowered, and during this fade the second mode has become apparent, *ie* it is only seen during a fade when the AGC level alters. The delay between the modes is comparable with that which would be expected between the arrival of signals via 1E and 1F modes. APPLAB merely predicts a 1E mode at this frequency. According to BLUEDECK, when present the F mode signal should have the greater amplitude but this was not seen.

When the frequency is between the MUF and LUF, *eg* 15036 kHz, there were regularly two modes seen (Fig 7). Once again BLUEDECK predicts more than one mode, the 1E and 1F, whereas APPLAB predicts single modes for the majority of occasions. For 1000 hours GMT, APPLAB predicts 1E and 1F₁ modes. The programs do not agree in other points such as signal amplitude. APPLAB predicts that when present, the 1F₁ is the weaker path, whereas BLUEDECK predicts 1F is stronger than the 1E. As may be seen in Fig 7, the results obtained using the different antennas available produced a strong E mode in the case of the Monopole and the Vertical log (Fig 7a&c) but in the case of the Horizontal log, the 1F mode was stronger (Fig 7b&d). When present, according to APPLAB, there is 100% reliability of both modes. BLUEDECK does not place such a high reliability on either of them, but it does conclude that the 1E is more reliable than the 1F (78% instead of 43%).

Using the frequency 8975 kHz, which is near the LUF, both programs predict the situation as seen, *ie* constant multimode. APPLAB predicts three modes, 1E, 2E and 4F₂. BLUEDECK predicts five modes, 1E, 2E, 2F, 3F and 4F. In practice, using this type of equipment, the 1E and 2E are unresolvable having a group delay separation less than 0.2 ms. It is possible from the photographs shown in Fig 8 to identify the 2E and the 2F mode in each of these cases. Fig 10 shows a schematic diagram of the pulses. There is a preceding mode in each of these, probably caused by Sporadic E. In Fig 10k there is an intermediate mode between the 2E and 2F, probably a mixed mode 1F, 2E. The following modes do not correspond to the group delays expected by either program for the multiple reflection modes. It is probable that these are mixed modes which neither BLUEDECK nor APPLAB predict, such as 2F, 1E₅ or M type (Fig 12), where reflection occurs from a Sporadic E layer, or likewise N type (Fig 13) which is another reflection mechanism from the Sporadic E layer, 1E₅, 1F.

When the two higher frequencies were being used, *ie* on the occasions where propagation occurred by only one or two modes, then the digital data was transmitted uncorrupted. Near the LUF, however, there were errors found in transmission when the noise level was high, *ie* data had been corrupted.

6 CONCLUSIONS

6.1 Assessment of flight trials data

It is believed that interpolating the ionospheric parameters over the polar and auroral zones using parameters from a UK ionosonde has limited use. This is due to the variability of the ionosphere with northerly latitude, particularly over these zones. The predictions made by APPLAB using stored data may be thought of as being more accurate than those using ionosonde data from Slough, or Slough and South Uist combined, as signals

were definitely received on the date in question at the specified time at Cobbett Hill. From the ICARUS analysis it can be inferred that multimode was employed in propagating the signal. Had the inference been that single mode propagation only was present there would still have been problems about accepting the APPLAB prediction using the combined Slough and South Uist data, as it predicts a very unreliable $1F_1$ mode. The $1F_1$ mode is unlikely at this time as the F_1 layer disappears during the night, and at the time of the trial, *ie* 0488 hours GMT, it will just be forming, so that if this mode were used it would be very unreliable. The signal, however, was strong and persistent at this time, indicating that another mode was used. It is reasonable to suppose the modes used were the $1F_2$ and $1F_2^H$.

6.2 Assessment of single pulse signals

This method of analysing a transmitted single pulse is useful for identifying major modes with a reasonable degree of accuracy. Thus it is possible to select one, two or many modes to be present based on APPLAB predictions which will be useful in future tests, where a vertically steerable antenna will be used to 'null out' unwanted modes.

As data is liable to corruption near the LUF due to the multipath and poor signal-to-noise ratio, it is advisable when transmitting digital data that a frequency substantially higher than the LUF be utilized. In this way, a signal is more likely to be correctly received after propagation by the ionosphere¹⁰.

Acknowledgments

The author wishes to thank Dr M. Lockwood for his help throughout this project. Also the staff of the radio stations in Bod~~ø~~ and Cobbett Hill who were involved in both sets of trials.

AppendixA LISTING OF PROGRAM IONPB WITH SUBROUTINE COORD1

```

~C
.R PIF
*TT1=IONPB.FOR
C      PROGRAM
C      EVALUATES IONOSPHERIC PARAMETERS AT POINT ALONG PATH
C      COORDS CALCULATED BY SUBROUTINE COORD1
C      USING OBSERVED DATA AT SOUTH UIST AND SLOUGH
C      ASS TT=7,TT=6 RKO=1,RKO=2
C      FTM1.DAT TO CONTAIN S.U. DATA
C      FTM2.DAT TO CONTAIN SLOUGH DATA
C      MAX NO OF POINTS ALONG PATH=20
C

C      DIMENSION ATX(10),ONX(10)
C      DIMENSION IVALS(12,4)
C      DIMENSION VAL(2,20,4),VALS(12,4),AVVAL(4)
C      VALS(I,1) TO CONTAIN FOF2
C      VALS(I,2)   '   '   FOE
C      VALS(I,3)   '   '   M3000F2
C      VALS(I,4)   '   '   H'F
C      I=1 IS TIME X,I=2 IS TIME X+15 MINS
C      ONSUD=7.14*(-1.0)
C      SOUTH UIST SOUNDER LONGITUDE
C      ONSLD=0.6*(-1.0)
C      SLOUGH SOUNDER LONGITUDE
C      PI=3.14159
C      PIT2=2.0*PI
C      ONSU=ONSUD*PI/180.0
C      ONSL=ONSLD*PI/180.0
C      CALL COORD1(ATX,ONX,N)
C      WRITE(7,710)
710 FORMAT(1H0,'1 FOR S.UIST DATA,-1 FOR SLOUGH DATA,',
1'2 FOR BOTH-I1')
      READ(7,721)ISELEC
721 FORMAT(I1)
      ISTART=1
      IF(ISELEC.EQ.-1)ISTART=2
      IFIN=2
      IF(ISELEC.EQ.1)IFIN=1
      DO 13 ICNT=ISTART,IFIN
      DO 1 IC=1,N
      IF(ONX(IC).GT.PI.AND.ONX(IC).LT.PIT2)ONX(IC)=ONX(IC)-PIT2
      IF(ICNT.EQ.1)ONSX=ONSU
      IF(ICNT.EQ.2)ONSX=ONSL
      OND=ONX(IC)-ONSX
      DLT=OND*24.0/PIT2
      IF(IC.NE.1)GO TO 3
      IF(ICNT.EQ.1)WRITE(7,711)
      IF(ICNT.EQ.2)WRITE(7,712)
711 FORMAT(1H0,'/,' SOUTH UIST')
712 FORMAT(1H0,'/,' SLOUGH')
      WRITE(7,700)
700 FORMAT(1H0,'G.M.T. OF H.F. SOUNDING,F5.2 FORMAT,DECIMAL HRS')
      READ(7,701)ZHS
701 FORMAT(F5.2)
      WRITE(7,702)
702 FORMAT(1H0,'G.M.T. OF FIRST IONOSONDE DATA(VALS(12,I))',
1'F5.2 FORMAT DECIMAL HOURS')
      READ(7,701)ZIS
      WRITE(7,704)
704 FORMAT(1H0,'SEPARATION OF SOUNDINGS,F5.2 FORMAT')
      READ(7,701)DZST
      READ(ICNT,705)(IVALS(K,1),K=1,12)
705 FORMAT(12(I3,1X))

```

```

        READ(ICNT,705)(IVALS(K,2),K=1,12)
        READ(ICNT,705)(IVALS(K,3),K=1,12)
        READ(ICNT,705)(IVALS(K,4),K=1,12)
708 FORMAT(12I5)
        DO 21 I21=1,12
        DO 22 I22=1,4
        VALS(I21,I22)=FLOAT(IVALS(I21,I22))
22 CONTINUE
21 CONTINUE
3 CONTINUE
        ZF=ZHS+DLT
        ZD=ZF-ZIS
        IZ=IFIX(ZD/DZST)+1
        IZ1=IZ+1
        FRAC=(ZD/DZST)-FLOAT(IZ-1)
        IER=0
        IF(IZ.LT.1)IER=1
        IF(IZ1.GT.12)IER=1
        IF(IER.EQ.1)GO TO 87
        DO 2 IC2=1,4
        VAL(ICNT,IC,IC2)=VALS(IZ,IC2)+(VALS(IZ1,IC2)-VALS(IZ,IC2))*FRAC
2 CONTINUE
        WRITE(6,601)IC,(VAL(ICNT,IC,K),K=1,4)
601 FORMAT(1HO,'POINT NUMBER ',I3,' :- FDF2= ',F6.2,
     1' : FOE= ',F6.2,' : M3000F2= ',F6.2,BH ' : F= ',F7.1)
1 CONTINUE
13 CONTINUE
        IF(ISELEC.NE.2)GO TO 87
        WRITE(6,607)
        DO 5 IC5=1,N
        ATXD=ATX(IC5)*180.0/PI
6 FRAC=(ATXD-51.7)/(57.2-51.7)
        DO 9 IC9=1,4
        AVVAL(IC9)=VAL(2,IC5,IC9)+FRAC*(VAL(1,IC5,IC9)-VAL(2,IC5,IC9))
9 CONTINUE
8 CONTINUE
        WRITE(6,601)IC5,(AVVAL(K),K=1,4)
607 FORMAT(1HO,'VALUES WEIGHTED ACCORDING TO LATITUDE')
5 CONTINUE
87 IF(IER.EQ.1)WRITE(6,600)IZ,IZ1,DLT
600 FORMAT(1HO,'ERROR ATTEMPT TO ACCESS OFF END OF ARRAY.'
     1'ELEMENT NUMBERS ',I4,' AND ',I4,'; 1HO,'LOCAL TIME DIFFERENCE',
     2'= 'F7.2)
        STOP
        END
#

```

```

SUBROUTINE COORD1(ATXA,ONXA,N)
  TO EVALUATE CO-ORDS OF N EQUALLY SPACED POINTS ALONG PATH
  ATS,ONS ARE RECEIVER LAT AND LONG,(RADS)
  ATO,ONO ARE TRANSMITTER LAT. AND LONG.(RADS)
  ISHORT=1 FOR LONG
  0FOR SHORT
  N=NO.OF POINTS ALONG PATH(<=10)
  RETURN LATS AND LONGS IN FIRST N ELEMENTS
  OF ARRAYS ATXA AND ONXA RESPECTIVELY
  ****
  DIMENSION ATXA(10),ONXA(10)
  PI=3.14159
  PI2=2.0*PI
  RE=6370.0
  H1=0.0000001
  PI2=PI/2.0
  4  WRITE(7,700)
 700 FORMAT(1HO,'INPUT COORDINATES-F7.2 FORMAT-IN DEGREES')
  WRITE(7,701)
 701 FORMAT(1HO,'RECEIVER LATITUDE? DEG. NORTH :')
  READ(7,711)ATSD
 711 FORMAT(F7.2)
  WRITE(7,702)
 702 FORMAT(1HO,'RECEIVER LONGITUDE-EAST OF GREENWICH: ')
  READ(7,711)ONS
  WRITE(7,703)
 703 FORMAT(1HO,'TRANSMITTER LATITUDE: ')
  READ (7,711)ATO
  WRITE (7,704)
 704 FORMAT(1HO,'TRANSMITTER LONGITUDE-EAST OF GREENWICH: ')
  READ(7,711)ONOD
 705 FORMAT(1HO,'NO.OF POINTS ALONG PATH?-(I2 FORMAT)')
  ONO=ONOD*PI/180.0
  ONS=ONS*PI/180.0
  ATO=ATO*PI/180.0
  ATS=ATSD*PI/180.0
  IF(ATO.EQ.PI2.OR.ATO.EQ.(PI2*(-1.0)))ONOD=ONS
  AOS=ABS(ONS-ONO)
  712 FORMAT(I2)
  C
  C   TO EVALUATE THE PATH CHARACTERISTICS AND
  C   WRITE THEM ALL OUT
  C
  S=SIN(ATO)
  ALPD=ACOS((SIN(ATS)*SIN(ATO))+(COS(ATS)*COS(ATO)*COS(AOS)))
  3  WRITE(7,706)
 706 FORMAT(1HO,'LONG OR SHORT GREAT CIRCLE PATH?/,/
  1  1HO,10X,'- ENTER 0 FOR SHORT AND 1 FOR LONG (I2 FORMAT)')
  READ(7,707)ISHORT
 707 FORMAT(I1)
  IF(ISHORT.EQ.1)WRITE(6,716)
  IF(ISHORT.EQ.0)WRITE(6,717)
 716 FORMAT(1HO,10X,'LONG GREAT CIRCLE PATH')
 717 FORMAT(1HO,10X,'SHORT GREAT CIRCLE PATH')
  ST=SIN(ATO)
  SR=SIN(ATS)

```

```

CT=COS(AT0)
CR=COS(ATS)
IF(AOS-H1)11,11,250
250 IF(ABS(AOS-PI)-H1)13,13,251
251 IF(PI2-ABS(AT0)-H1)11,11,252
252 IF(PI2-ABS(ATS)-H1)11,11,253
253 SRR=SIN(ALPD)
COR=COS(ALPD)/SRR
ARG1=SR/(CT*SRR)-ST*COR/CT
ARG2=ST/(CR*SRR)-SR*COR/CR
BO=ACOS(ARG1)
BS=ACOS(ARG2)
IF(AOS-PI)14,17,17
14 IF(ONO.GT.ONS)BO=PIT2-BO
IF(ONS.GT.ONO)BS=PIT2-BS
GO TO 6
17 IF(ONS.GT.ONO)BO=PIT2-BO
IF(ONO.GT.ONS)BS=PIT2-BS
GO TO 6
11 IF(ATS-AT0)12,300,300
300 BO=0.0
BS=PI
GO TO 6
12 BO=PI
BS=0.0
GO TO 6
13 IF(ATS+AT0)100,100,15
100 BO=PI
BS=PI
GO TO 6
15 BO=0.0
BS=0.0
6 CONTINUE
IF(ISSHORT.EQ.0)GO TO 5
ALPD=2.0*PI-ALPD
BO=PI+BO
BS=PI+BS
IF(BO.GE.PIT2)BO=BO-PIT2
IF(BS.GE.PIT2)BS=BS-PIT2
5 CONTINUE
WRITE(6,713)ATSD,ONOD
713 FORMAT(1H0,10X,'TRANSMITTER ,T : ',F7.2,
1 ' N. ',F7.2,' E. (DEG.)')
WRITE(6,714)ATSD,ONSD
714 FORMAT(1H0,10X,'RECEIVER ,R : ',F7.2,
1 ' N. ',F7.2,' E. (DEG.)')
BOD=BO*180.0/PI
BSD=BS*180.0/PI
ALPDD=ALPD*180.0/PI
D=ALPDD*111.136
WRITE(6,715)ALPDD,D,BOD,BSD
715 FORMAT(1H0,10X,'ANGULAR PATH LENGTH : ',
1 F6.2,' PATH LENGTH : ',F10.2,' KM. ',/1H0,10X,
2 'BEARINGS IN DEG. E. OF N. : ',/1H0,35X,
3 'OF R AT T = ',F6.2,/1H0,35X,
4 'OF T AT R = ',F6.2)
2 WRITE(7,705)
READ(7,712)N
C
C TO EVALUATE N POINTS ALONG THIS PATH
CX
C
C
C
C
C
C
IF(N.EQ.0)GO TO 10

```

```

DO 1 IC=1,N
SKIP=D$FLOAT(IC)/FLOAT(N+1)
AN=SKIP/RE
ATX=ASIN(SIN(AT0)*COS(AN)+COS(AT0)*SIN(AN)*COS(BO))
DIFF=ON0-ON0
IF(SKIP.LT.0.0)DIFF=DIFF*(-1.0)
IF(ABS(BO)-H1)36,36,350
350 IF(ABS(BO-PI)-H1)36,36,351
351 ARG=(COS(AN)-SIN(ATX)*SIN(AT0))/(COS(ATX)*COS(AT0))
ANL=PI-(AT0+ATX)
IF(AN.LE.ANL)ADX=ACOS(ARG)
IF(AN.GT.ANL)ADX=PI2-ACOS(ARG)
GO TO 310
36 ADX=0.0
IF(AT0*COS(BO)+AN-PI2)33,33,352
352 ADX=PI
IF((AT0*COS(BO)+AN).GT.(PI+PI2))ADX=0.0
GO TO 33
310 IF(DIFF)32,37,31
31 IF(DIFF-PI)33,33,34
32 IF(DIFF+PI)33,34,34
33 ONX=ON0-(FLOAT(2*ISHORT-1))*ADX
GO TO 35
34 ONX=ON0+(FLOAT(2*ISHORT-1))*ADX
35 IF(ONX)450,323,323
450 ONX=ONX+PI2
323 IF(PI2-ONX)396,396,38
396 ONX=ONX-PI2
GO TO 38
37 ONX=ON0
38 CONTINUE
ATXD=ATX*180.0/PI
ONXD=ONX*180.0/PI
ATXA(IC)=ATX
ON>A(IC)=ONX
WRITE(6,722)IC,ATXD,ONXD
722 FORMAT(1HO,10X,'POINT NO.:',I3,3X,'LATITUDE=',F7.2,3X,
1'LONGITUDE=',F7.2,3X,'DEGREES EAST OF GREENWICH.')
1 CONTINUE
10 CONTINUE
RETURN
END
FUNCTION ACOS(X)
PI=3.14159
IPV=0
IF(X.LT.0.0)IPV=1
IF(IPV.EQ.1)X=X*(-1.0)
IF(X.EQ.1.0)GO TO 2
IF(X.EQ.0.0)GO TO 1
T1X=1.0/(X*X)
T2X=SQRT(T1X-1.0)
ACOS=ATAN(T2X)
1 IF(X.EQ.0.0)ACOS=PI/2.0
2 IF(X.EQ.1.0)ACOS=0.0
IF(IPV.EQ.1)ACOS=PI-ACOS
RETURN
END
FUNCTION ASIN(X)
PI=3.14159
IPV=0
IF(X.LT.0.0)IPV=1
IF(IPV.EQ.1)X=X*(-1.0)
IF(X.EQ.1.0)GO TO 2
IF(X.EQ.0.0)GO TO 1
T1X=1.0/(X*X)
T2X=SQRT(T1X-1.0)
ASIN=ATAN(1.0/T2X)
1 IF(X.EQ.0.0)ASIN=0.0
2 IF(X.EQ.1.0)ASIN=PI/2.0
IF(IPV.EQ.1)ASIN=ASIN*(-1.0)
RETURN
END

```

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PROGRAM APPLAB 3:HF SKY-WAVE FIELD-STRENGTH PREDICTION VERSION 10

PREDICTION 02/06/80-1141 FOR APRIL 1980 WITH SUNSPOT NO. 158.0

	LAT	LNG	AZIMUTH	WEIGHT (FEET)	TYPE ANTENNA POL
TX PLANE (8000 FEET)	71.21	22.28	219.55	30000	ISOTROPIC H POL
RX COBBETT HILL	51.25	150.40	19.15	0	ISOTROPIC V POL
N.MILES			S.MILES	KM	
RANGE	1349.25		1552.60		2608.81

TX POWER 0.10 KW NOISE POWER BANDWIDTH 1 Hz

REGN. S/N POWER RATING (TX RX KW) 20.00 dB 3 dB NOISE (IN 1 Hz BW) -150.0 dB

IONOSPHERE PRENTED MEDIAN , UPPER AND LOWER RECILES

Fig 1a APPLAB predictions using predicted ionosphere

Fig 1a

Fig 1a (continued)

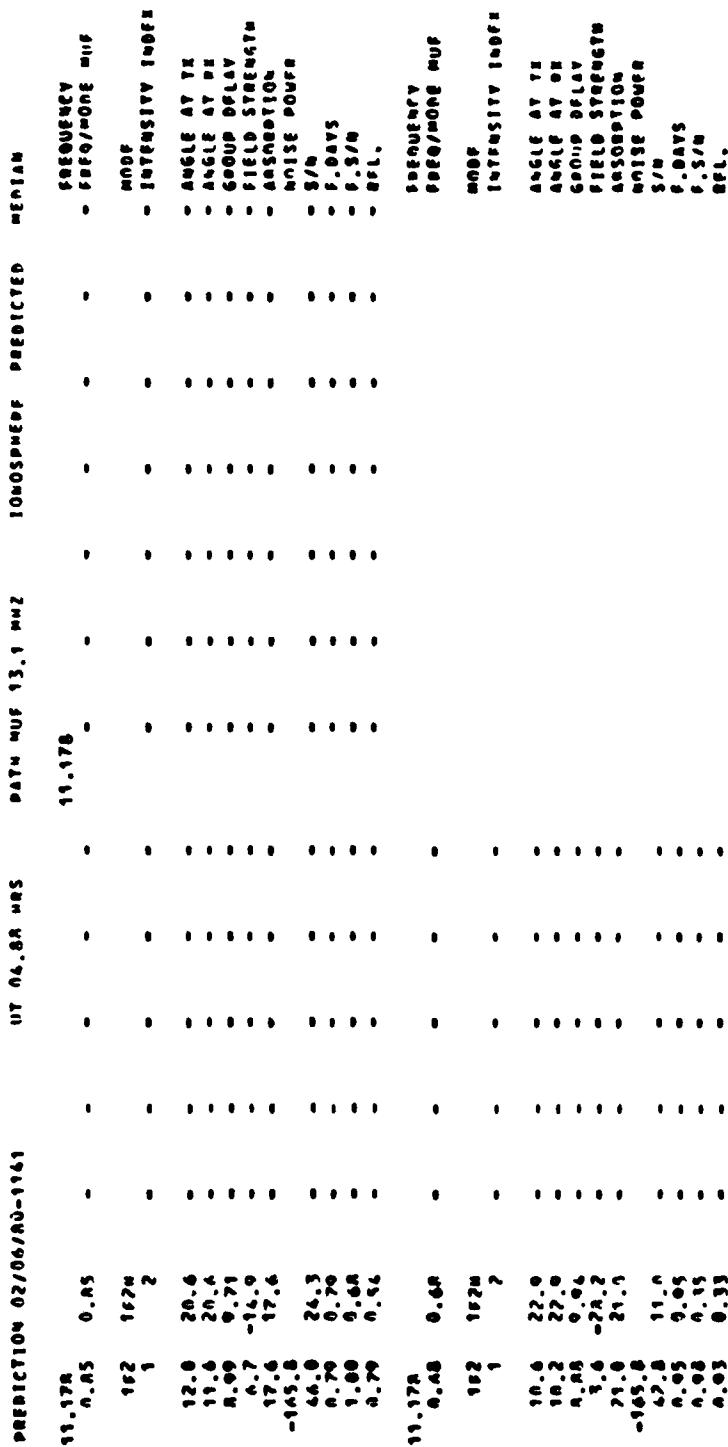


Fig 1 a (continued)

Fig 1b

PROGRAM APPLAB 3: HF SKY-WAVE FIELD-STRENGTH PREDICTION VERSION 1B

PREDICTION 28/05/80-1021 FOR APRIL 1980 WITH SUNSPOT NO. 158.0

	LAT	LONG	AZIMUTH	HEIGHT (FEET)	ANTENNA TYPE	POL
TX FLANE (BODO TRIALS)	71.21	22.28	219.55	30000	ISOTROPIC	H POL
RX COBBETT HILL	51.25	359.40	19.13	0	ISOTROPIC	V POL
	N.MILES		S.MILES		KM	
RANGE	1349.25		1552.69		2498.81	
TX POWER 0.10 KW						
NOISE POWER BANDWIDTH 1 HZ						
REQD. S/N POWER RATIO (IN RX BW) 20.00 DB	3 MHZ NOISE (IN 1 HZ BW) -150.0 DBW					

IONOSPHERE	MEASURED	MEDIAN
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MEASURED IONOSPHERIC CHARACTERISTICS FOR UT 0400

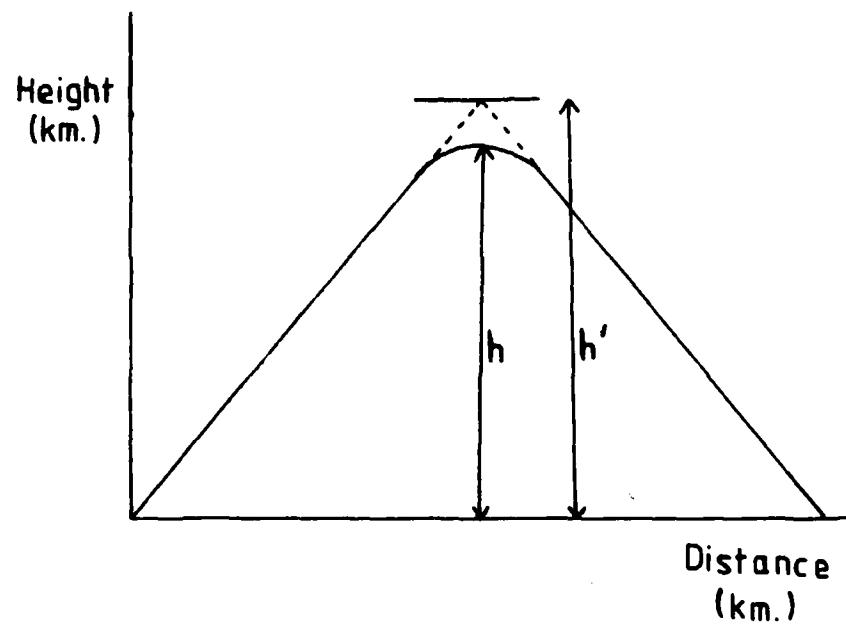
SITE	LAT	LONG	FOF2	H(3000)F2	FOE	H'FF2
1	66.61	13.25	3.93	3.31	2.26	261
2	61.67	7.13	4.05	2.84	2.13	291
3	56.52	2.74	4.50	2.59	1.73	294

PREDICTION 28/05/80-1021 UT 04.00 HRS PATH MUF 11.5 MHZ IONOSPHERIC MEASURED MEDIAN

11.178	-	-	-	-	-	-	FREQUENCY
1.05	-	-	-	-	-	-	FREQ/MODE MUF
1F1	-	-	-	-	-	-	MODE
1	-	-	-	-	-	-	INTENSITY INDEX
6.8	-	-	-	-	-	-	ANGLE AT TX
6.1	-	-	-	-	-	-	ANGLE AT RX
0.67	-	-	-	-	-	-	GROUP DELAY
-6.7	-	-	-	-	-	-	FIELD STRENGTH
3.0.0	-	-	-	-	-	-	ABSORPTION
-165.8	-	-	-	-	-	-	NOISE POWER
32.5	-	-	-	-	-	-	S/N
0.10	-	-	-	-	-	-	F. DAYS
0.68	-	-	-	-	-	-	F. S/N
0.08	-	-	-	-	-	-	REL.
8	-	-	-	-	-	-	

Fig 1b APPLAB predictions using measured ionosphere

Fig 2



h = actual height of layer

h' = apparent height of layer

Fig 2 Difference between real and apparent height of layer

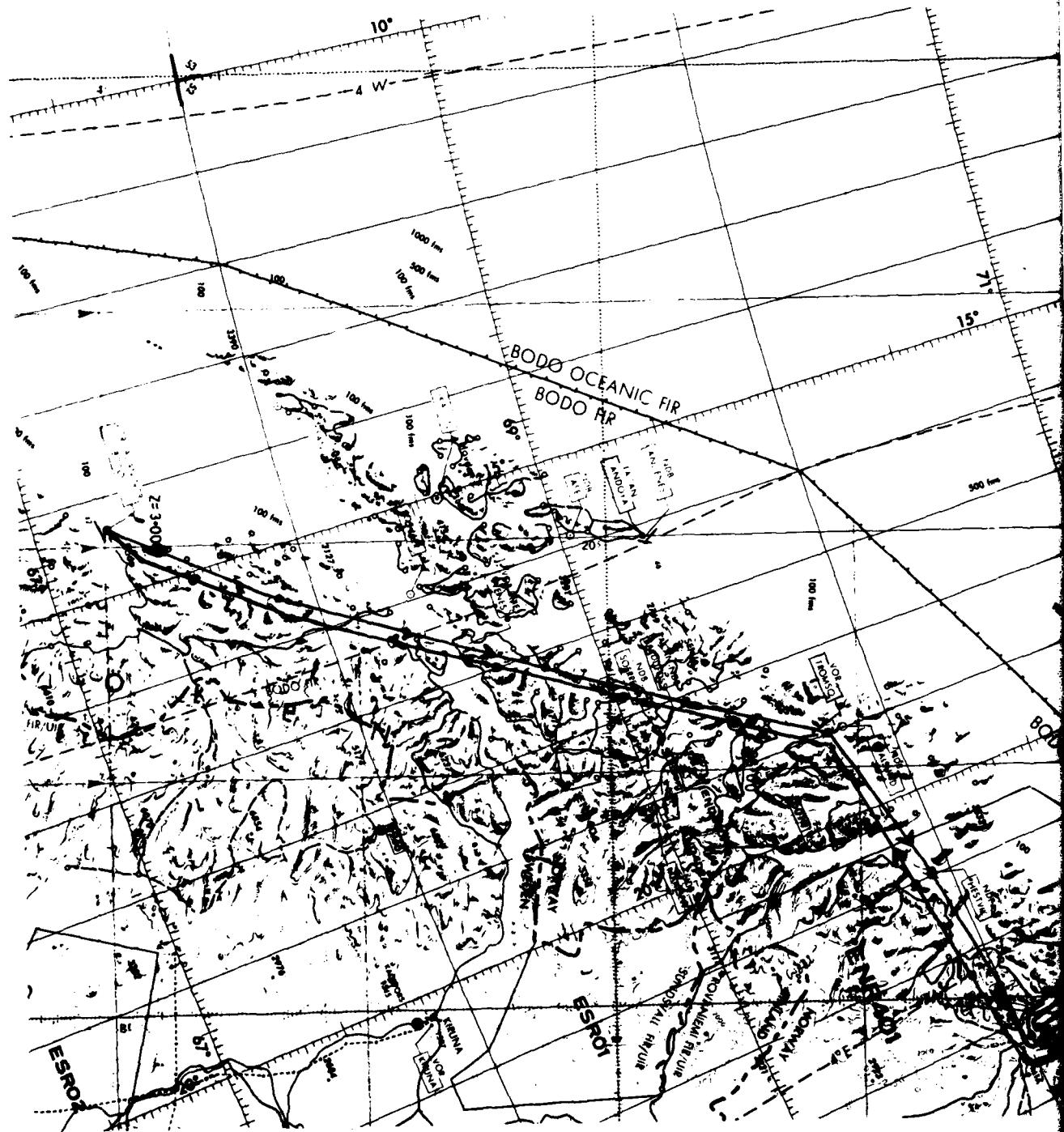
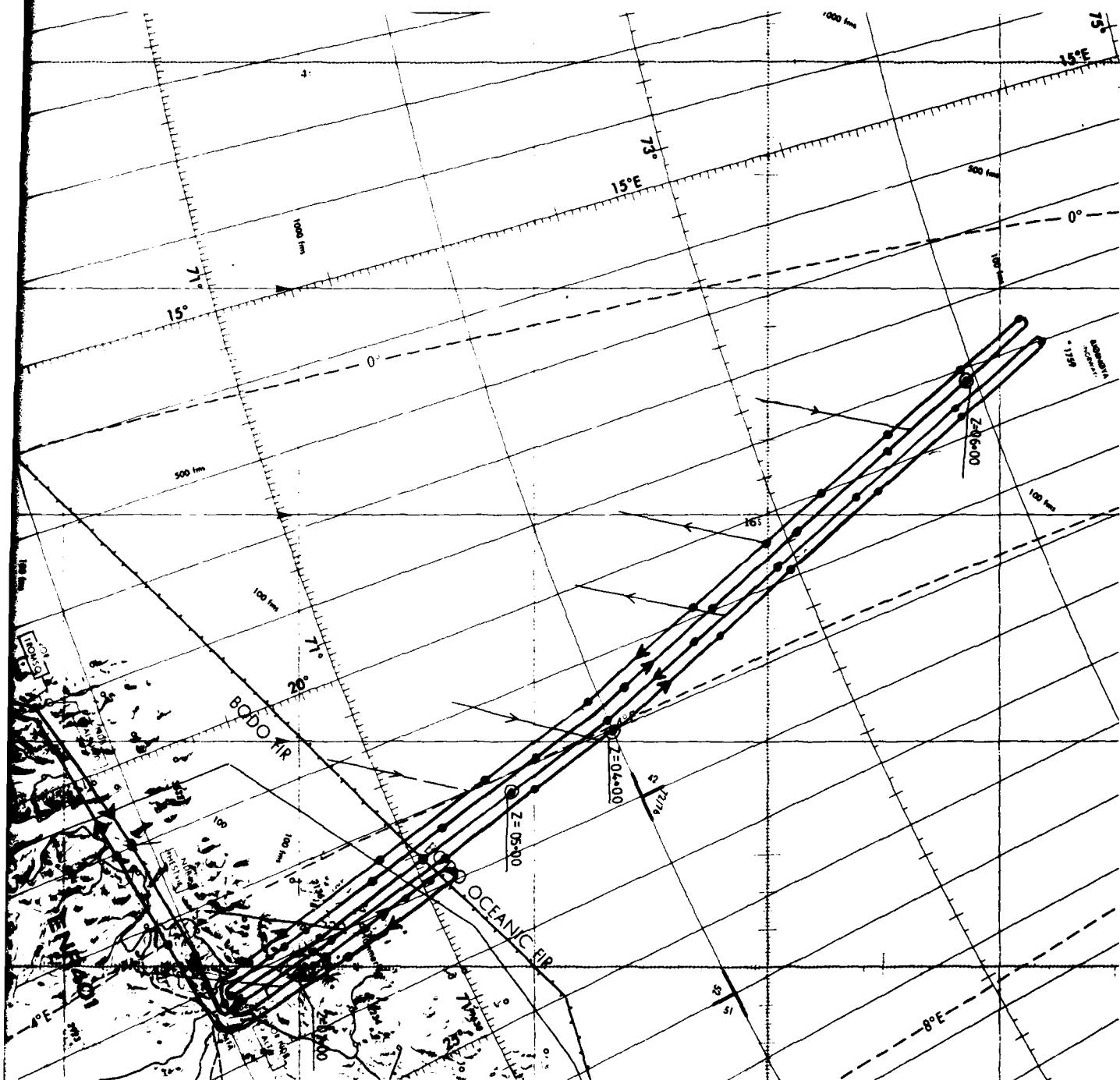


Fig 3 Flight path of aircraft between 16 April 1980

Fig 3



Flight path of aircraft between BODO and Bear Island
16 April 1980

Fig 4

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15 min.
CS	SP	SP	SP	75D	OFF	75D	OFF	600D	OFF	75D	OFF	75D	OFF	75D	OFF	

CS=Call Sign

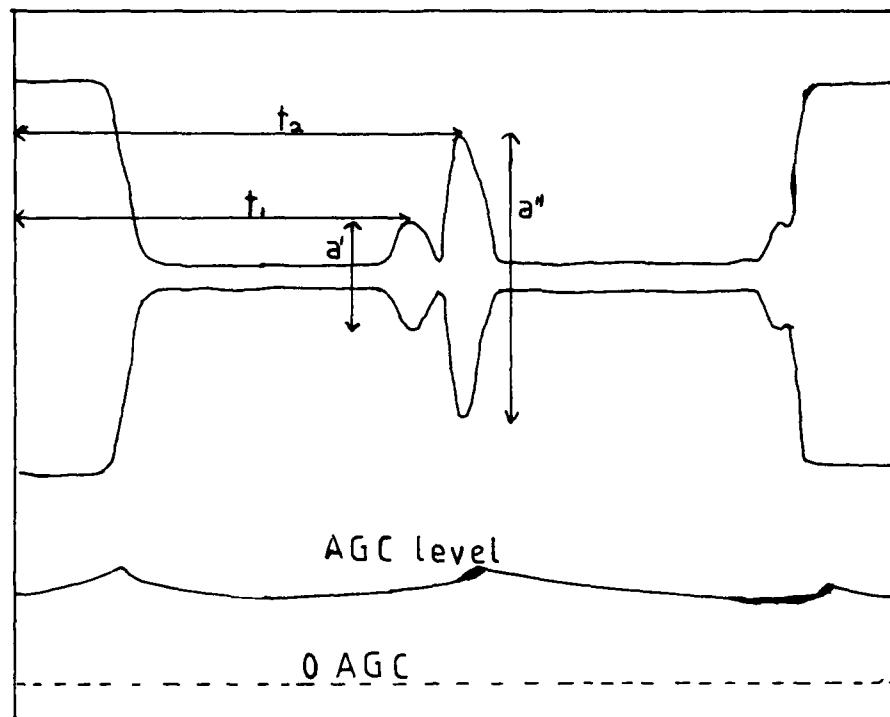
SP= Single Pulse

75D= 75 baud data

600D = 600 baud data

Fig 4 Fifteen minute cycle of data generator

Fig 5



$$a_1 = \frac{a'}{2} \quad a_2 = \frac{a''}{2}$$

$$\Delta t_1 = t_2 - t_1$$

Fig 6a&b

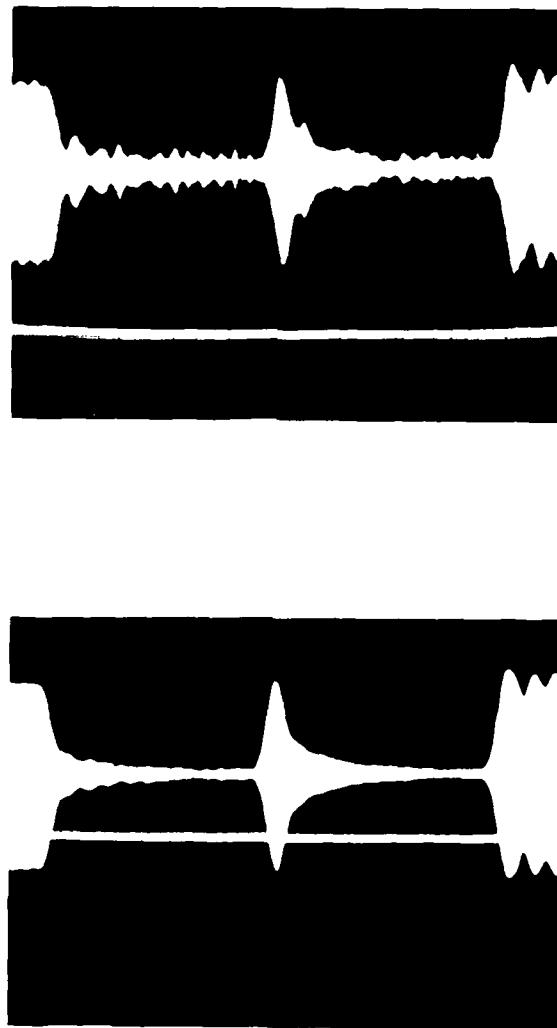


Fig 6a&b Single pulse transmissions 20 June 1980

Fig 6c



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Fig 6c Single pulse transmissions 20 June 1980

Fig 7a&b



Fig 7a&b Single pulse transmissions 23 June 1980

Fig 7c&d

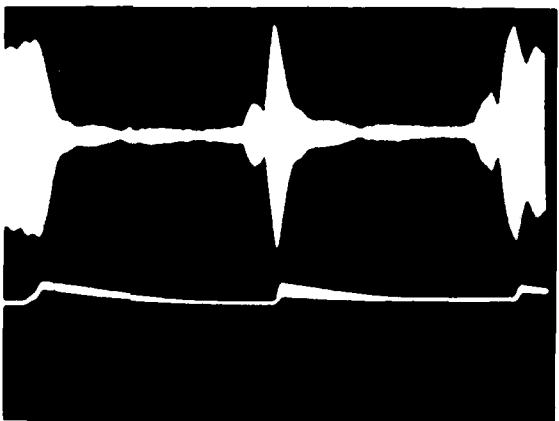
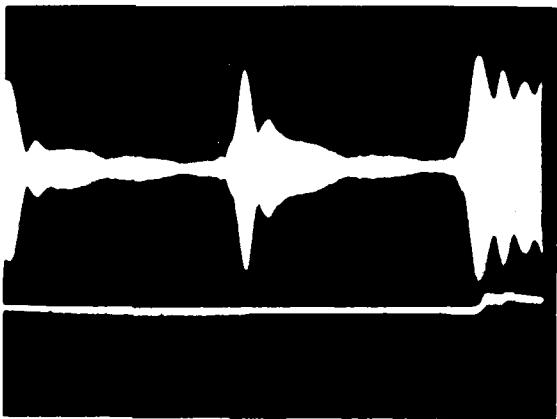


Fig 7c&d Single pulse transmissions 23 June 1980

Fig 8a&b

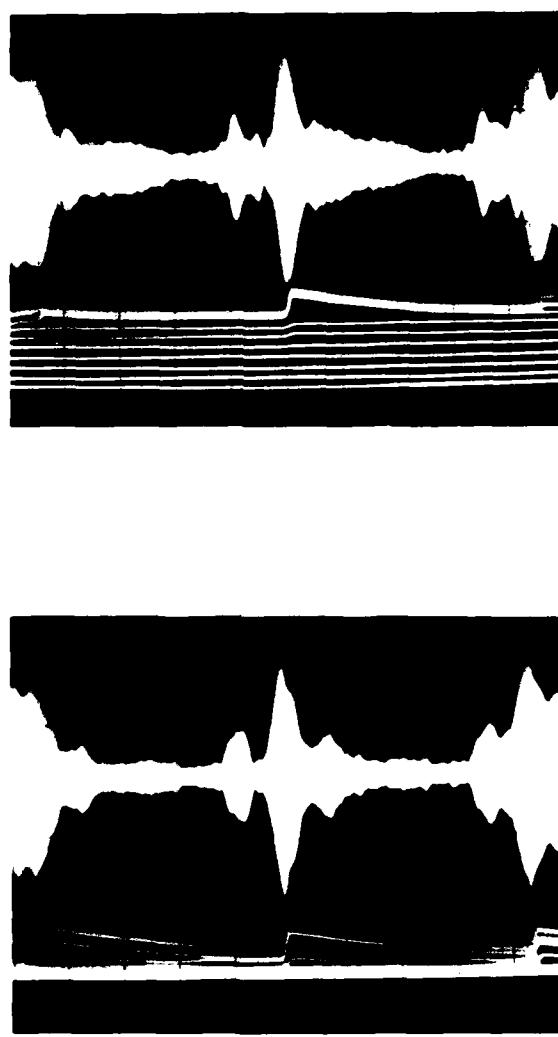
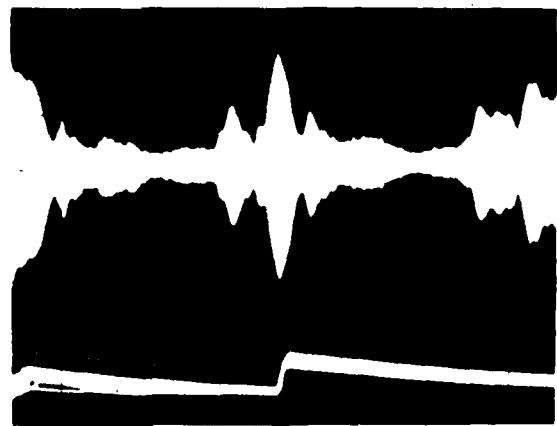
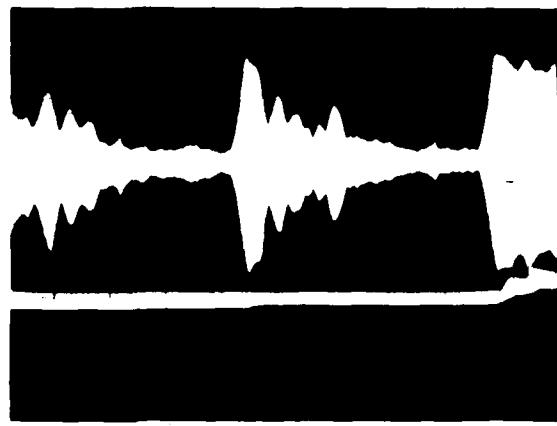


Fig 8a&b Single pulse transmissions 25 June 1980

Fig 8c&d



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Fig 8c&d Single pulse transmissions 25 June 1980

Fig 9

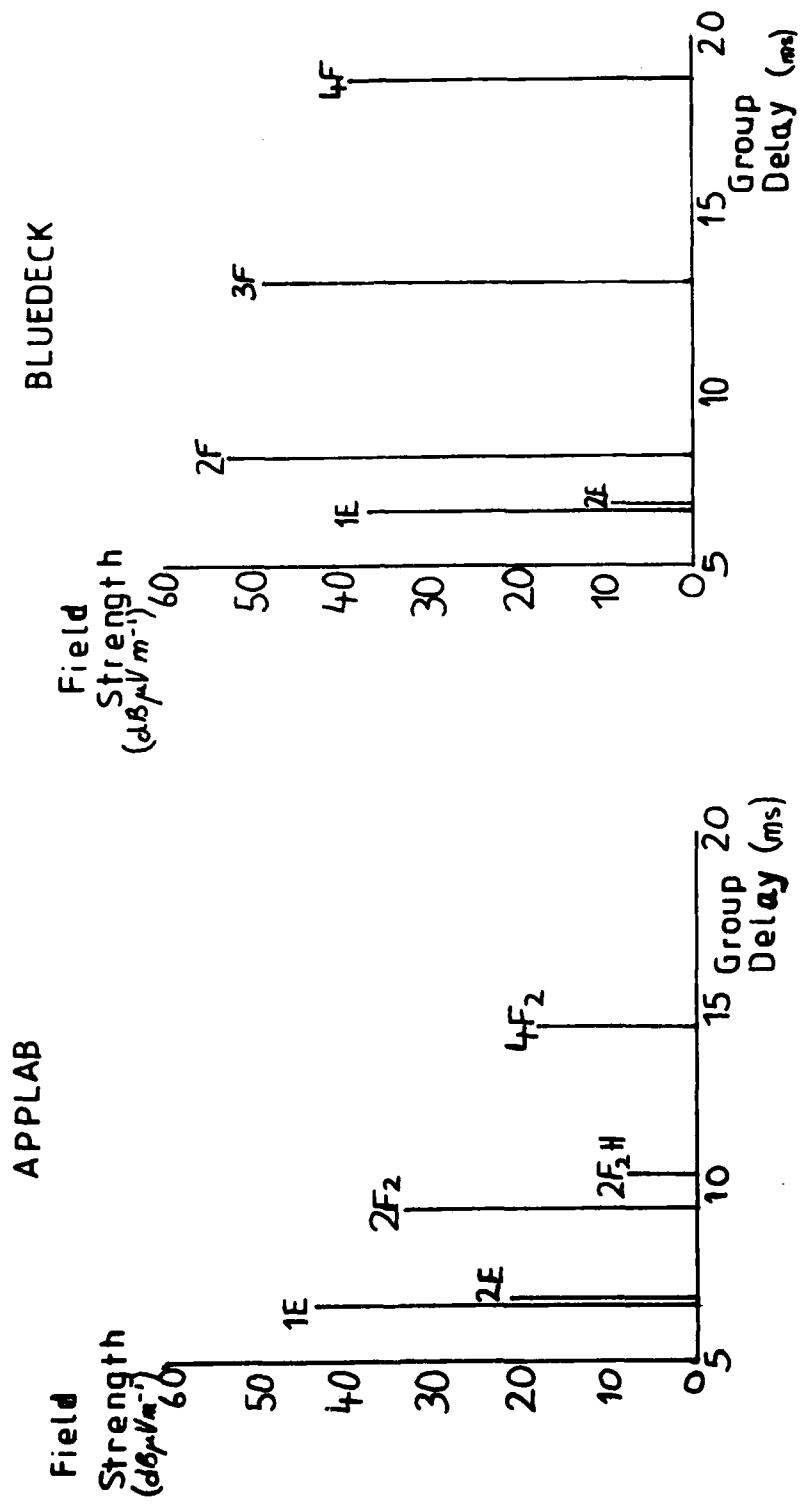


Fig 9 APPLAB and BLUEDECK predictions for 25 June 1980

Fig 10a-c

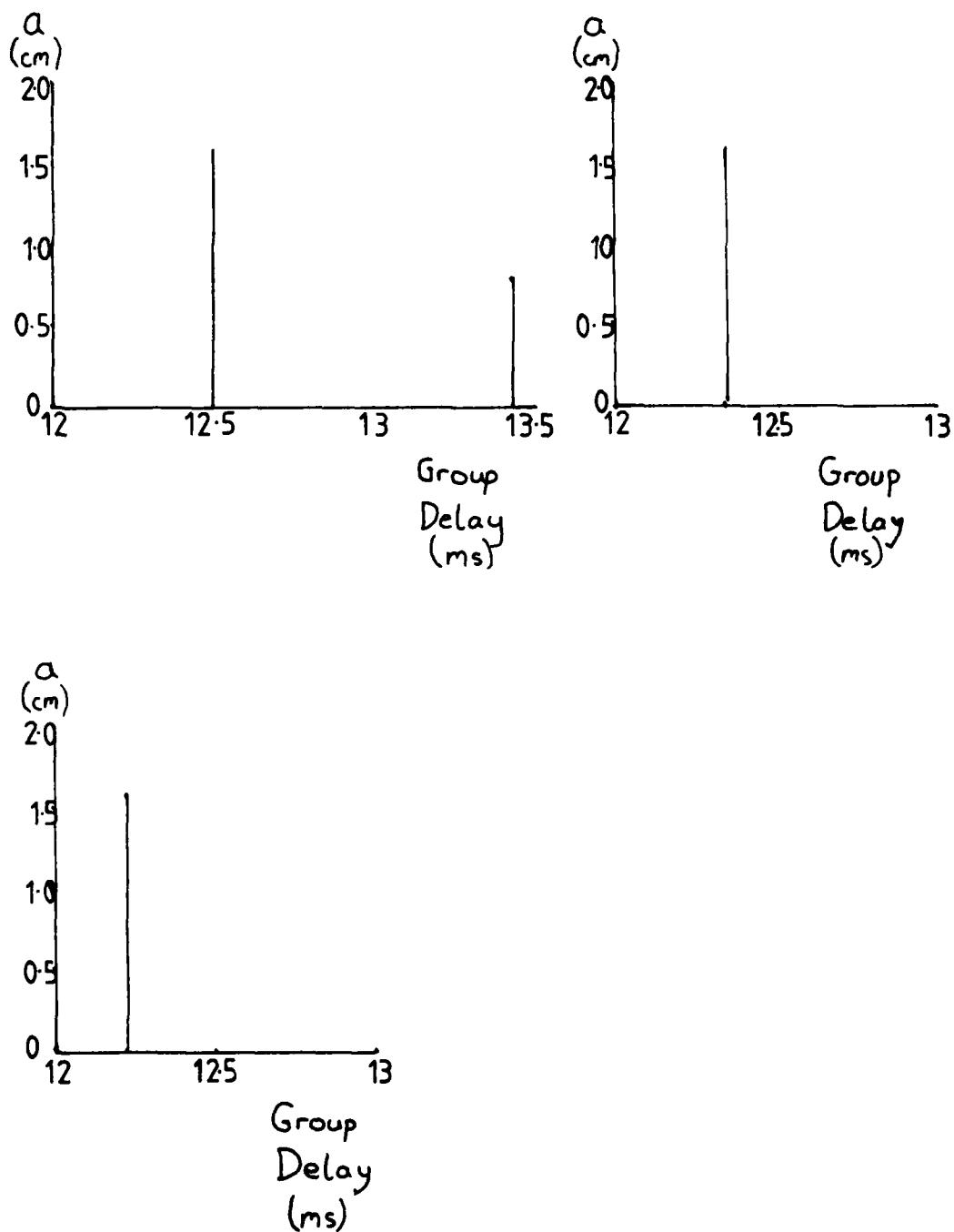


Fig 10a-c Analysis of photographs for 20 June 1980. Frequency 18025 kHz

Fig 10d-g

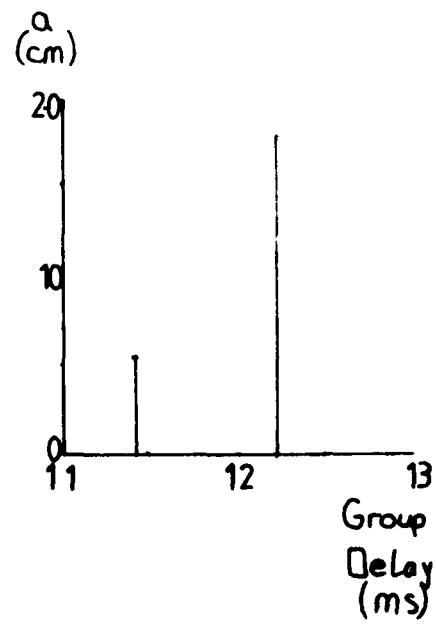
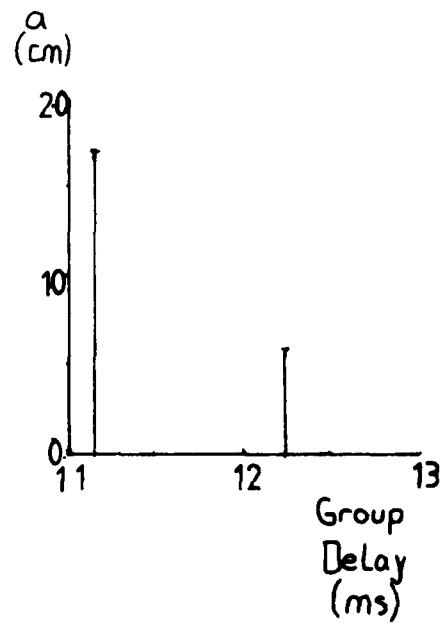
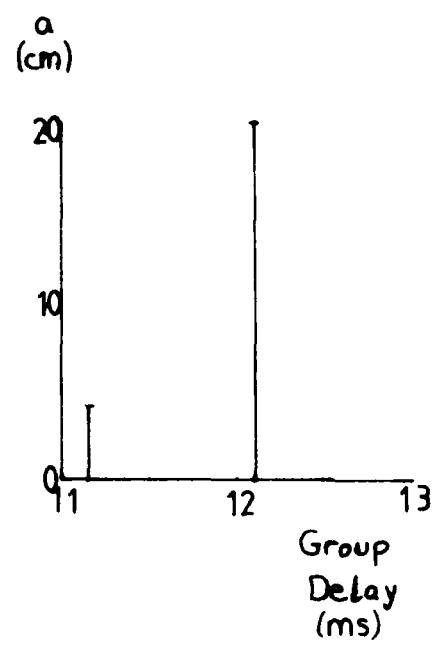
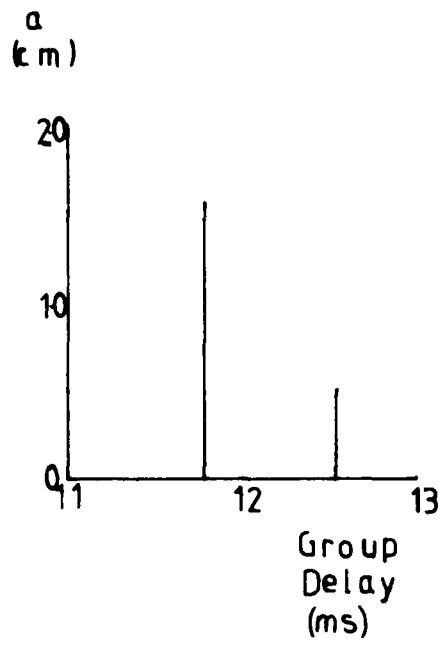
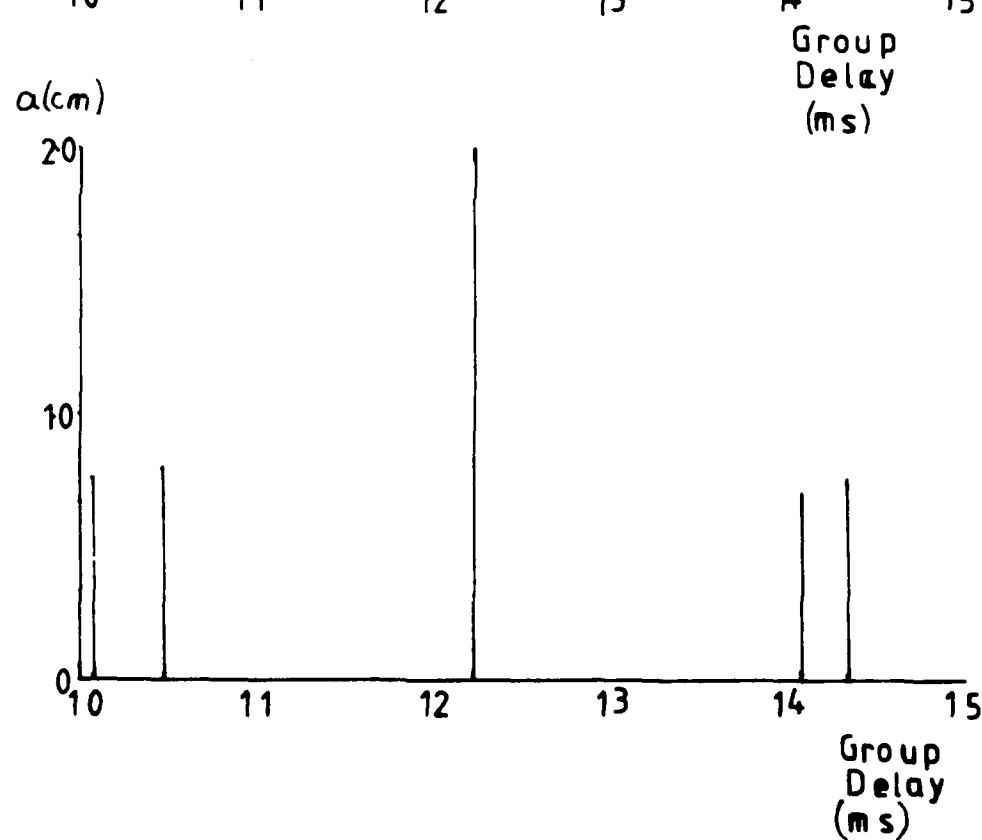
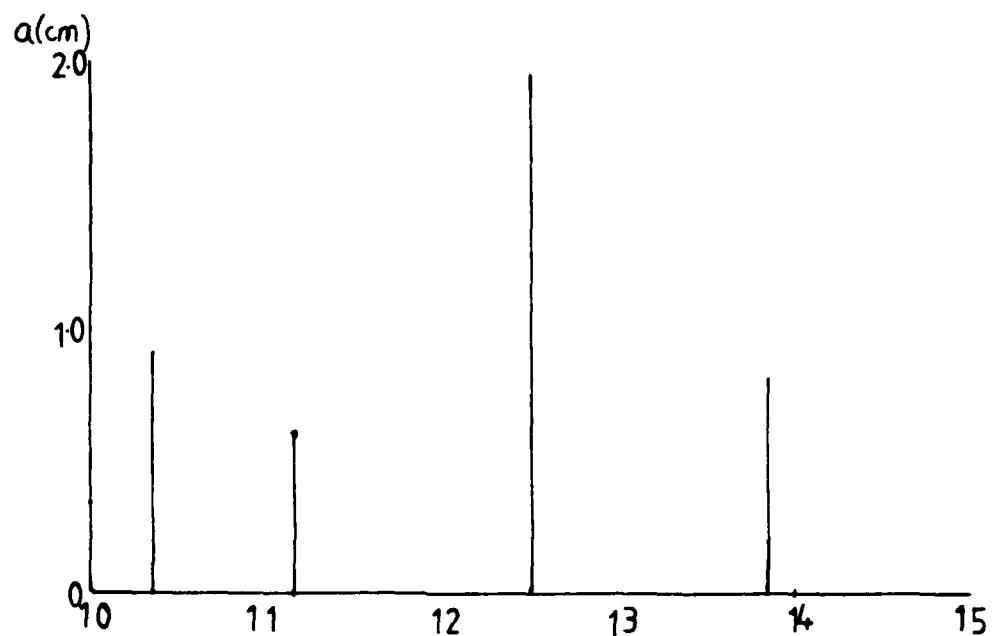


Fig 10d-g Analysis of photographs for 23 June 1980. Frequency 15036 kHz

Fig 10h&i



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Fig 10h&i Analysis of photographs for 25 June 1980. Frequency 8975 kHz

Fig 10j&k

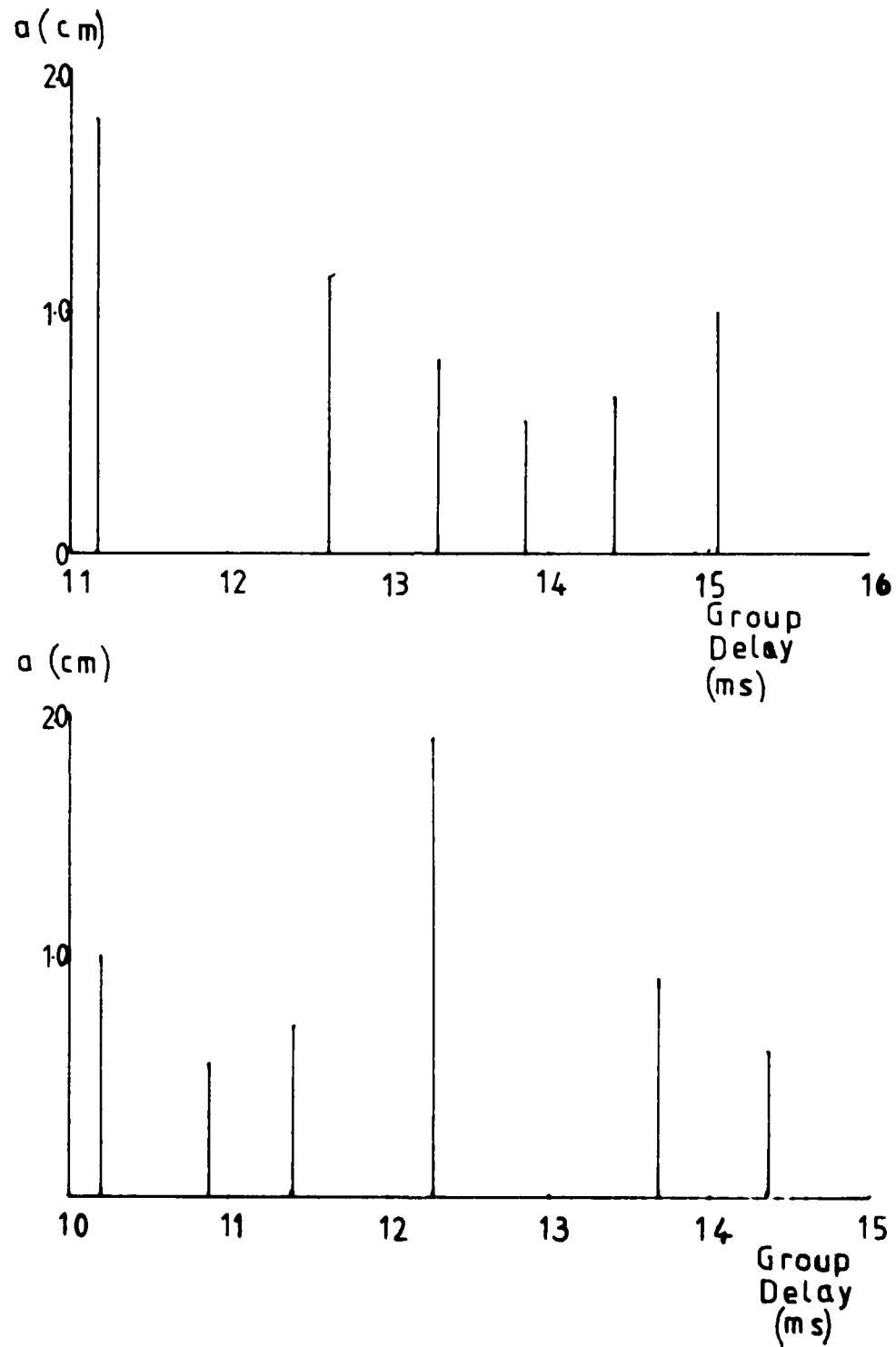
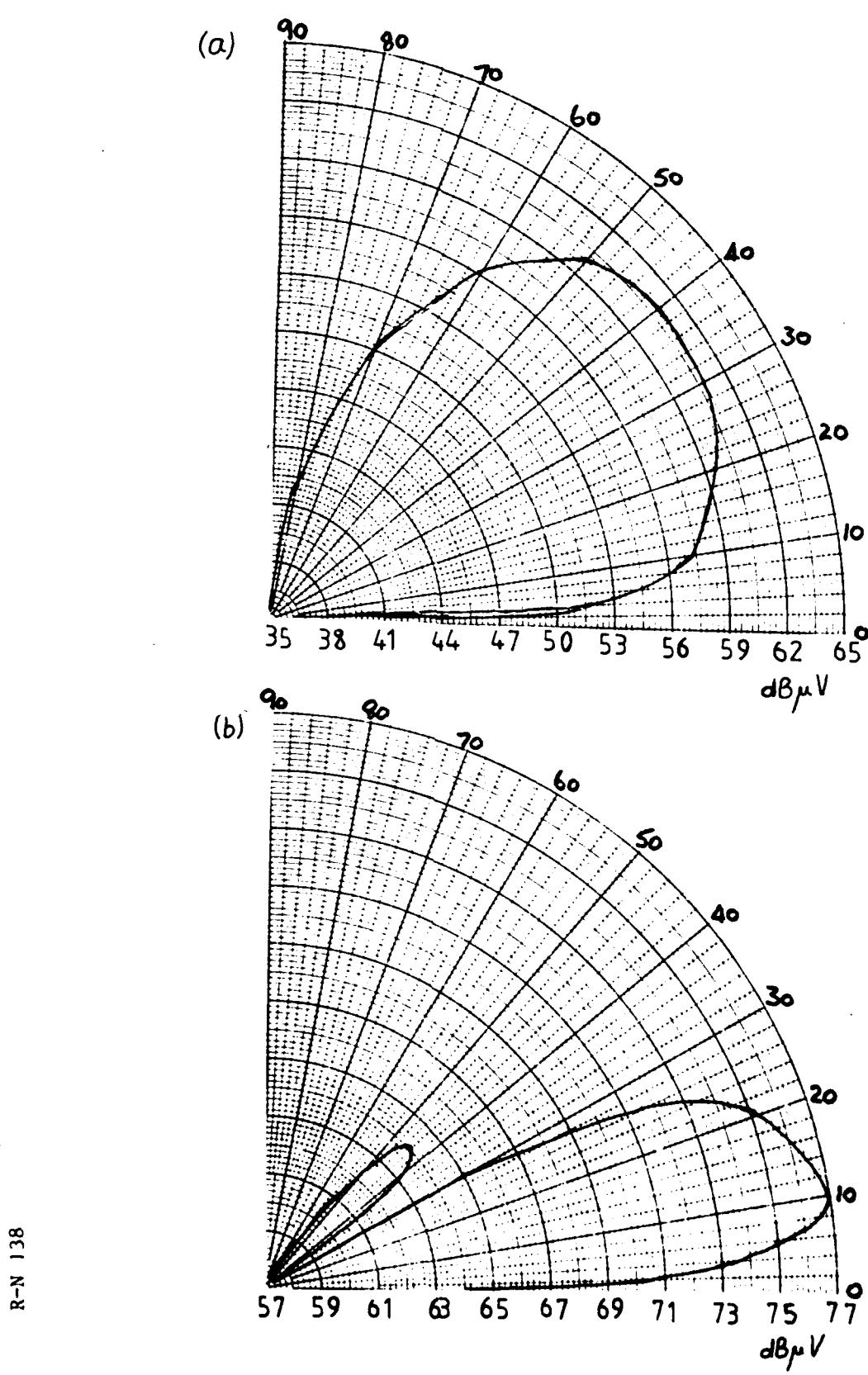


Fig 10j&k Analysis of photographs for 25 June 1980. Frequency 8975 kHz

Fig 11



R-N 138

Fig 11 Examples of response of (a) high elevation angle and (b) low elevation angle antennas at 8975 kHz

Figs 12&13

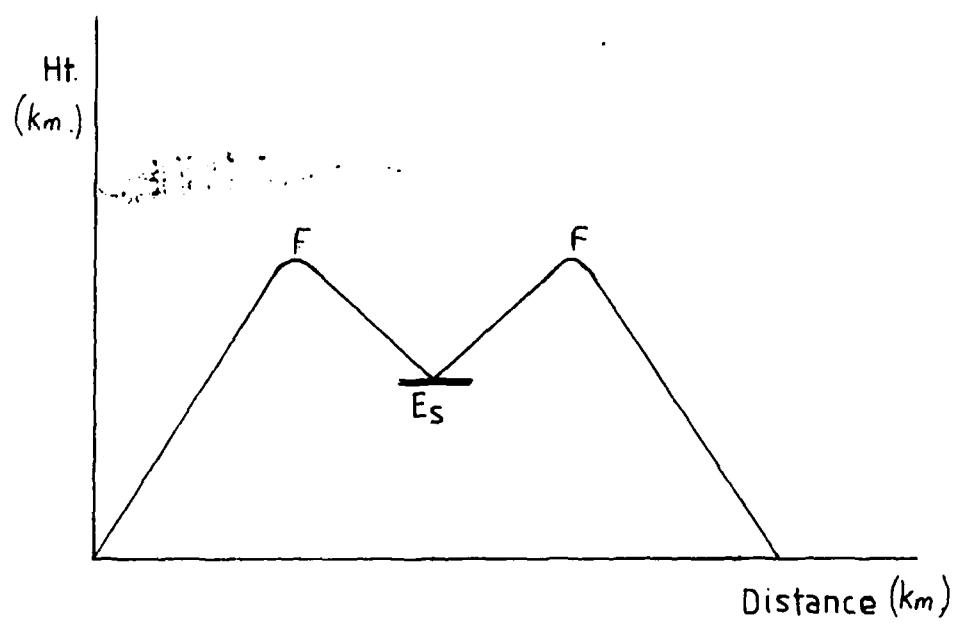


Fig 12 'M' type reflection from Sporadic E layer

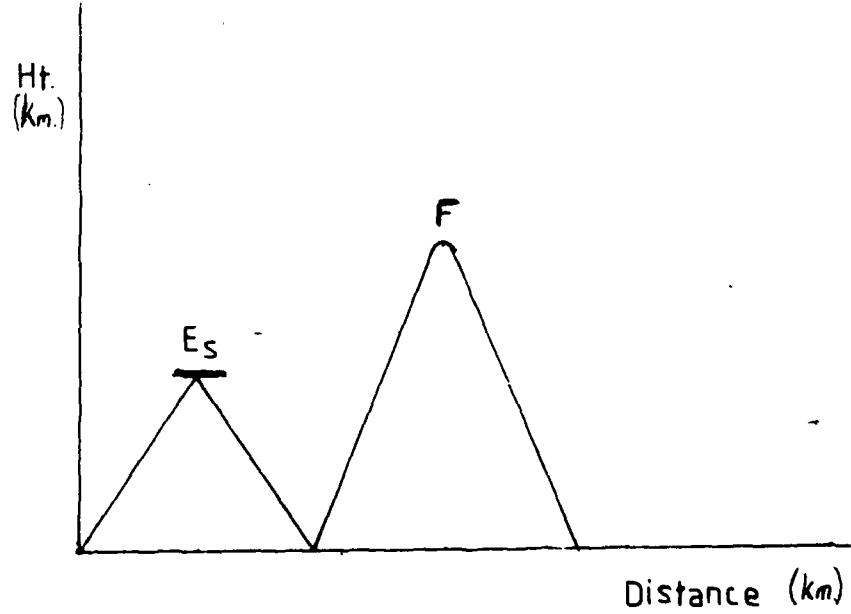


Fig 13 'N' type reflection from Sporadic E layer

REPORT DOCUMENTATION PAGE

Overall security classification of this page

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11. Contract Number N/A	12. Period N/A	13. Project Ionosphere. HF. Propagation. Auroral.	14. Other Reference Nos.
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16. Descriptors (Keywords) (Descriptors marked * are selected from TEST) Ionosphere. HF. Propagation. Auroral.			
17. Abstract Methods of determining the usable frequencies over a particular auroral sub-auroral path such that digital data may be sent uncorrupted, are described. Tests took place between April and July 1980 using transmissions between Northern Norway and Southern England. Computer programs were used in order to determine the viability of linearly interpolating the ionospheric propagation parameters from sub-auroral areas to an auroral or polar zone. One of these programs was written for this project and is included. The others are in general use and are, therefore, not listed. It was found that interpolation of the ionospheric parameters over these zones has limited use.			

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